DEVELOPMENT OF A LOW-COST SOFTWARE FOR 2D DEFORMATION DETECTION IN GEODETIC NETWORK

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ABSTRACT

Deformation monitoring in Malaysia has become more important nowadays due to the increasing risk of hazardous tragedies such as landslide, subsidence and structural movement in engineering structures. This paper focuses on the development of a low-cost software for deformation detection using Fredericton approach (2D applications). This in-house software (FREDY03) is developed under windows environment. Fredericton approach, which is based on the analysis of the invariant functions of displacements, concisely performs the analysis and least squares fitting of changes of distances and angles derived from the adjusted (minimum constraints) coordinates. This software consists of two modules: least square estimation (LSE) and deformation detection analysis. For verification, the results from FREDY03 are compared to our in-house software, DEFORM99 (via Congruency Testing). The results indicate that both approaches (Fredericton vs Congruency) give similar outcome on the stability status of the monitoring stations. Consequently, users can determine deformation detection between two epochs using the developed low-cost software.

1. INTRODUCTION

Nowadays, there are many softwares that have been designed to perform deformation analysis in geodetic network. These softwares, either being developed commercially or research purpose, use various of methods and quite expensive (e.g. ALERT, DIMONS, DREAMS, etc). Although these softwares have proven to perform the deformation analysis excellently, there are several other approaches to the analysis of deformation micro-geodetic network that can be implemented throughout computer programs, and one of them is Fredericton approach.

Therefore, a low-cost software has been developed in Survey Engineering Research Group (SERG), formerly known as Center for Industrial Survey and Engineering Survey (CIMES) to conduct least square estimation and deformation analysis via Fredericton approach. The software is called FREDY03 and was developed within windows-environment with attached help file.

2. FREDERICTON APPROACH

Fredericton approach was invented by Prof Adam Chrzanowski of University of News Brunswick and was presented in FIG commission in 1981. It is based on the analysis of invariant functions of displacements. The determinations of displacements are datum independent because the derived changes of observation vectors (Δl) are invariant quantities. In other words, regardless of which stations are used to define the datum, as long as both epochs use the same datum, the result will be the same (Secord, 1981). Fredericton approach includes four phases:

1. Data screening & preliminary determination of deformation trends.
2. Single point displacements analysis in reference network.
3. Relative displacements in relative network.
4. Physical interpretation.

In Fredericton approach, the adjusted coordinates available are subjected to minimum constraint adjustment. If one of the minimally constraint point is found to have moved, the only effect on the resultant coordinate set will be a rigid-body translation or rotation. The use of multiple fixed points or weighted stations would cause distortions if an unstable reference point were present (Chrzanowski, 1981).

Then, the adjusted parameters and its variance-covariance matrices of both epochs will be used for computing the quasi observation of the network. Quasi observation will include quasi distances and quasi angles. Assume that a, b and c are the stations in a triangulation network:

Quasi observation of angles:

$$\beta_{abc} = \mathrm{Tan}^{-1}[(X_c - X_a)/(Y_c - Y_a)] - \mathrm{Tan}^{-1}[(X_b - X_a)/(Y_b - Y_a)] \qquad (1a)$$

Quasi observation of distances:

$$d_{ab} = [(Y_b - Y_a)^2 + (X_b - X_a)^2]^{1/2} \qquad (1b)$$

where:

X_a, Y_a = coordinate of station A
X_b, Y_b = coordinate of station B
X_c, Y_c = coordinate of station C

Where as p is the number of stations in the subjected network, total of angle quasi in the network is p (p – 1) and total of distance quasi in the network is [p (p – 1)] / 2 (Zainal, 1997). The computed quasi observation will be used in the one dimension F-Test. The one dimensional F-Test is written as (Chrzanowski, 1981):

$$\frac{\Delta lk}{\sqrt{(\sigma^2 \Delta lk)}} < \sqrt{F(1,\ df1+df2,\ \alpha)} \tag{2}$$

df1	: degree of freedom of epoch 1
df2	: degree of freedom of epoch 2
Δlk	: differences of derived vector of observation k of epoch 1 and 2
$\sigma^2\Delta lk$	: variance of differences of observation k (i.e. diagonal element of matrix variance k observation)
α	: significance, usually at 0.05 level

Arising from the failure of this test is the suspicion that any of the members of the observation stations is significantly unstable. Unfortunately, the quasi observation of distance is due to the changing of the scale, during the measurement. Therefore, the present concern to deliberate the failing observation is the distance element (Secord, 1981).

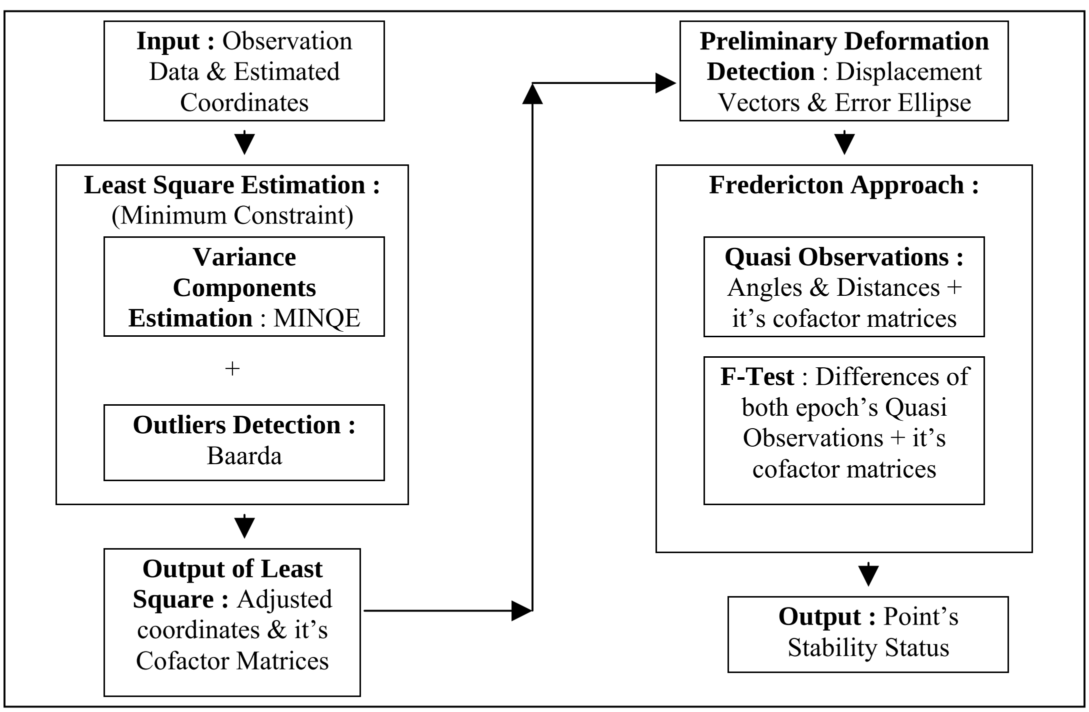

Figure 1 : Procedure of Fredericton analysis

3. SOFTWARE COMPONENTS

There are four components in FREDY03 (Figure 1). These components are linked to each other, as illustrated in Figure 2.

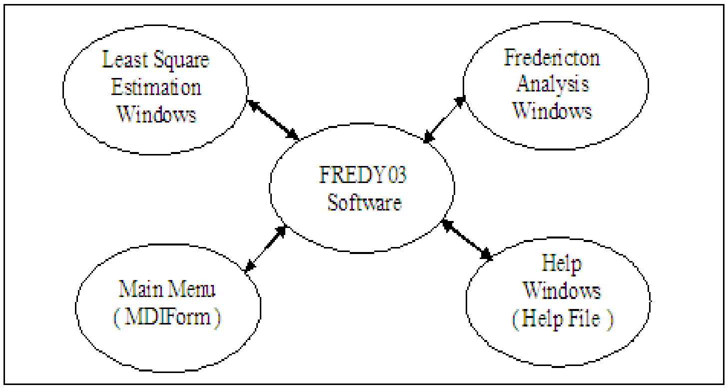

Figure 2 : FREDY03 Components

Of all the components stated above, the Least Square Estimation module and Fredericton Analysis module are the most important module.

3.1 Least Square Estimation Module.

In this module, Minimum Constraint solution is used for the least square computation. The computation took place in an executable FORTRAN file. The results include; Baarda Test results, number of iteration involved, final adjusted parameters for both epochs and their cofactor matrices, final standard errors, etc. The results also include the results of preliminary deformation detection (i.e. displacement vectors, displacements azimuth, ellipse orientation, magnitude of semi-major/minor of the ellipses etc).

One of the special features of FREDY03 is the use of MINQE (Minimum Norm Quadratic Estimation) routine to perform the estimation of the variance components for LSE calculations. MINQE is well known as the best way to estimate the variance components as it can provide a value, closest to the value that recommended by the instrument manufacture. In FREDY03, the users can view the result of the MINQE routine and can even save it electively. However, the computation of MINQE is performed independently in Least Square Estimation computation module.

3.2 Fredericton Analysis Module

In this module, Fredericton Analysis process (via Points Segregation Analysis) is performed. This includes the computations and designing scheme of adjusted quasi observation (of both epochs) and its cofactor matrices and the differences of quasi observations (i.e. magnitude).

One-dimensional F-Test with significance level of 0.05 (i.e. 95% confidence level) will be tested on the differences. The results of point stability is shown here. Users can process their data without going through the adjustment module first because their data will automatically run through adjustment mode in this process. This will help users interpret their raw data freely. The results will be shown in text editor where users can edit, save and even print the results.

4. IMPACT OF MINIMUM CONSTRAINT SOLUTION

The choice of minimum constraint is arbitrary because regardless of the location or orientation of configuration, the results of the F-Test will be the same. The individual least squares adjustments provide estimated coordinates with maximum likelihood but with values dependent on the points chosen to constraint the configuration in the coordinate space, while the figure itself is the most probable fit to the observations.

Therefore, as long as the same constraint serve as the adjustment base in both epochs, these derived observations are suitable for comparisons in investigating the stability of the points. The only inconsistencies, over and above errors in positions of the points, are reflected in the cofactor matrix of the parameters, resulting from the displacement of the points during the interval between two epochs.

Analysis has been made throughout a simulation data using different definition of datum (Suhaida, 1999). The simulation data has six stations and point 3 is simulated as moved point. The total number of quasi observation is 20. Table 1 shows the results using FREDY03.

Table 1 : Numbers of failing quasi observations in each station

Station	Datum definition						Total of Failure
	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	
1	10	7	10	11	14	16	68
2	12	11	13	14	15	17	82
3	20	20	20	20	20	20	120
4	11	9	10	12	13	16	71
5	11	9	12	11	12	17	72
6	11	8	11	12	12	19	73

With the total failure of 120 quasi observations, station 3 remains as an unstable point regardless of datum definition in the adjustment. This proved that in the process of Fredericton analysis, the datum definition in minimum constraint adjustment did not effect the result of points segregation in the subjected network.

5. COMPARISON WITH DEFORM99

5.1 Comparison of Results

Using a simulation data set (Ranjit, 1997), results of FREDY03 was then being compared to Deform99 (Ong, 1999) software. There are six stations in the network and points 4 and 5 are well known as unstable points. Station 1, 2 and 3 are the reference stations.

The result of FREDY03 was the same as Deform99. Stated as the highest total of failing quasi observation in the F-Test, station 4 and 5 is proved as unstable. Table 2 shows the comparisons of both software.

Table 2 : Comparison of results from Deform99 and FREDY03

Station	Deform99 F computations	Fredy03 Total failure of F-test	
1	2.299	9	(Stable)
2	1.963	7	(Stable)
3	1.43	6	(Stable)
4	1562.36	11	**(Unstable)**
5	528.893	11	**(Unstable)**
6	0.576	6	(Stable)

Even though both softwares use different approaches, the results are still the same. Hence, FREDY03 can be used for deformation detection, as the results of point stability are as the same as Deform99.

5.2 Comparison of Help File.

In Deform99, help file is not included. Help file, which can be develop under Microsoft Visual Pro Help 4.0, has a very big impact on software where it can automatically become more user-friendly.

The most important and basic information that user should know when operating the program is the format of the input data. With the help file (Figure 4), user can easily rearrange their data for the processing and operate the software easily.

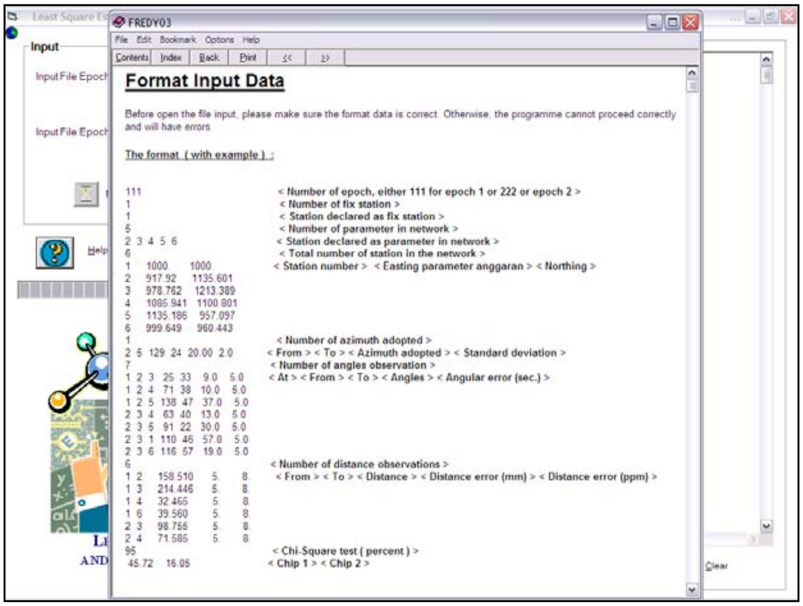

Figure 4 : Format input data in Help File

5.3 Comparison of Practical Capability

Using FREDY03, deformation detection can be easily done. This is because, in practical applications, users did not actually know if the reference stations are unstable or not and the most important issue is either the stations in the network are stable or not.

Using Fredericton Approach, where the datum is not a factor that matter to stand out the segregation of the points, we can easily apply it and moved points can be detected. In another view, FREDY03 has practical capability because of its windows-based interface where users of all range of knowledge can easily used it, compared to the FORTRAN language software that is not practical enough to this routine.

6.0 CONCLUSION

FREDY03 is a user-friendly, effective software and can be used practically to perform deformation detection in any personal computer or workstation (Ernyza, 2003). It is compatible to any Microsoft Windows version (e.g. Windows 1998/XP/2000/NT) and its GUI is easily understandable. Using Fredericton approach to detect point's segregation, FREDY03 can be a prime or alternative software to any other software available. It is also a low-cost software that had been developed so far.

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